Ground Motion Simulation Validation using Small-to-Moderate Magnitude Events in the Canterbury, New Zealand Region

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1. Background and Objectives

This poster presents work to date on ground motion simulation validation and inversion for the Canterbury, New Zealand region. Recent developments have focused on the collection of different earthquake sources and the verification of the SPECFEM3D software package in forward and inverse simulations. SPECFEM3D is an open source software package which simulates seismic wave propagation and performs adjoint tomography based upon the spectral-element method.

By understanding the predictive and inversion capabilities of SPECFEM3D, the current 3D Canterbury Velocity Model can be iteratively improved to better predict the observed ground motions. This is achieved by minimizing the misfit between observed and simulated ground motions using the built-in optimization algorithm.

Figure 1 shows the Canterbury Velocity Model domain considered including the locations of small-to-moderate M_w events [3-4.5], strong motion stations, and ray paths of observed ground motions. The area covered by the ray paths essentially indicates the area of the model which will be most affected by the waveform inversion. The seismic sources used in the ground motion simulations are centroid moment tensor solutions obtained from GeoNet. All earthquake ruptures are modelled as point sources with a Gaussian source time function. The minimum M_w limit is enforced to ensure good signal-to-noise ratio and well constrained source parameters. The maximum M_w limit is enforced to ensure the point source approximation is valid and to minimize off-fault nonlinear effects.

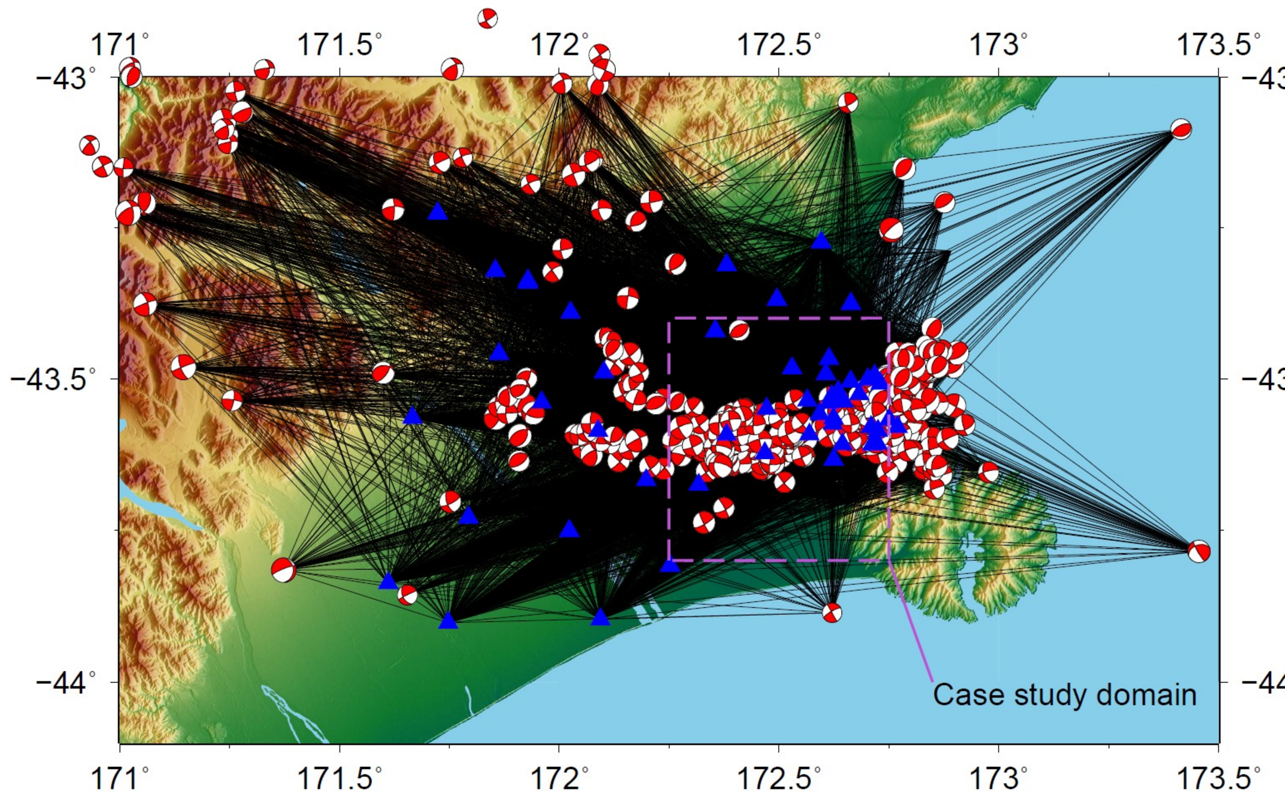

Figure 1: The Canterbury Velocity Model domain with locations of small-to-moderate M_w sources, strong motion stations and corresponding ground motion ray paths.

2. Velocity Model

In order to benchmark the implementation and predictive capability of SPECFEM3D for Canterbury applications, the ground motions simulated using SPECFEM3D are compared against both observed ground motions and simulated ground motions obtained using other simulation methodologies. Simulated ground motions for comparison are produced via the deterministic finite difference ground motion simulation methodology proposed by Graves and Pitarka (2010) (GP) for both a 1D and 3D velocity model of the Canterbury region. The 1D and 3D models are presented here in the form of fence diagrams of shear wave velocity, in Figures 2a and 2b respectively, to highlight the salient features of each model. The geographic locations of the cross sections are shown in the inset map.

- The 1D velocity model is a modified version of the South Island 1D velocity model developed by Ristau (2008) (which was based on first arrival times of reference events) specifically for use in the Canterbury region. As shown, the seismic velocities increase monotonically with depth across the entire region.
- The 3D velocity model was developed by Lee et al. (2016) utilizing several geologic and geophysical data sources such as seismic reflection lines, geologic cross sections, and petroleum exploration well logs. The region is characterized by soft sedimentary deposits in the Canterbury Basin and the high-velocity Banks Peninsula volcanics shown in cross section 2, both of which have been shown to strongly influence wave propagation and the resulting ground motions.

As the 3D Canterbury Velocity Model has been built from geologic and geophysical data, the observed ground motions (a seismological data source) can be used to independently improve the velocity model.

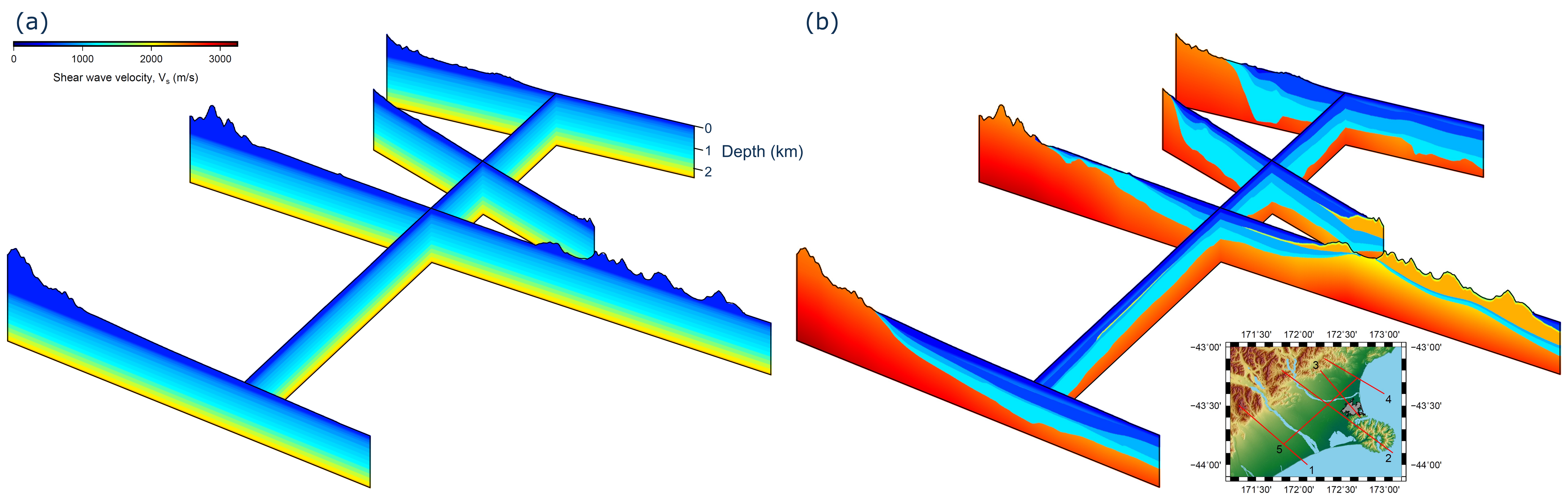

Figure 2: Fence diagrams of shear wave velocities highlighting the salient features of the (a) 1D Canterbury velocity model, and (b) 3D Canterbury velocity model.

3. Ground Motion Simulation Results

The 19th October 2010 M_w 4.8 event has been used as a case study for benchmarking and verifying the implementation of the SPECFEM3D software package. The domain, source and strong motion station locations are shown in Figure 3. The resulting simulated ground motions from SPECFEM3D are compared with numerical solutions obtained by researchers using GP for both 1D and 3D velocity models, as well as with observed ground motions. The results of the ground motion simulations are presented here for three sites; Cashmere High School (CMHS), Lincoln (LINC) and Canterbury Aero Club (CACS) in Figures 4a, 4b and 4c, respectively.

- The 1D simulation results for SPECFEM3D and GP are in agreement for all sites. When compared to observed ground motions the first arrival times are consistent but there are noticeable differences in amplitudes, duration and frequency content.
- The 3D simulation results for SPECFEM3D and GP agree to varying extents. Between simulation results, the CMHS site has the best agreement followed by the LINC site and lastly the CACS site. While only the CMHS simulation results strongly resemble its corresponding observed ground motion, there are some similarities in amplitudes and frequency content at the other sites.

There are important differences between finite difference and spectral element methods which can lead to these differences in simulation results. In particular, for strongly heterogeneous models, such as the 3D Canterbury Velocity Model, the interpolation of the model between discretizations is evaluated differently. 1D velocity models are less affected by these differences in simulation methodology.

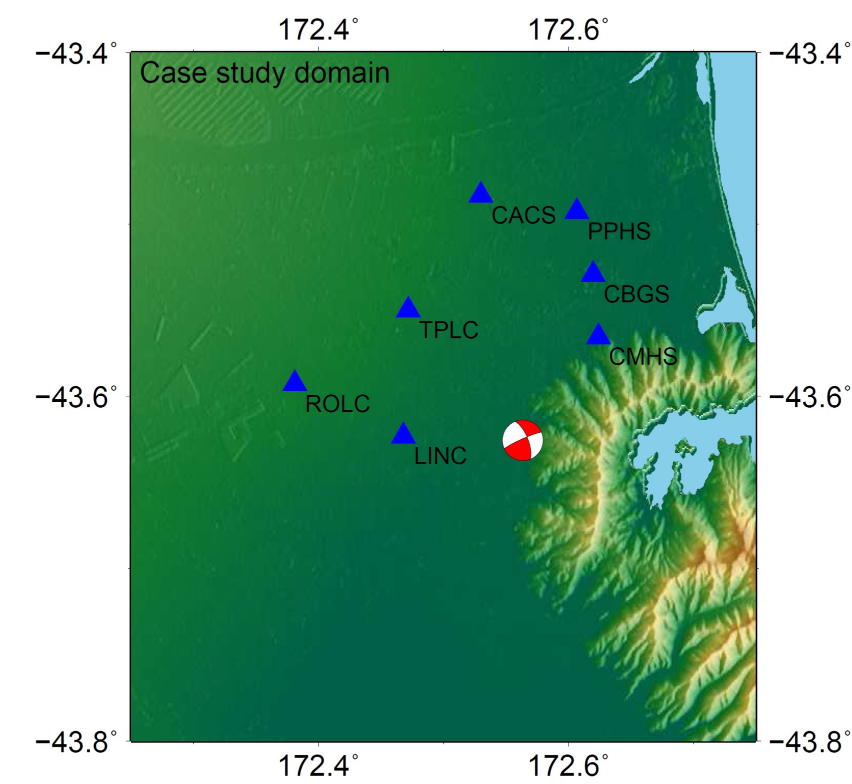

Figure 3: Domain used for the 19th October 2010 M_w 4.8 case study event including the location of the seismic source and strong motion stations.

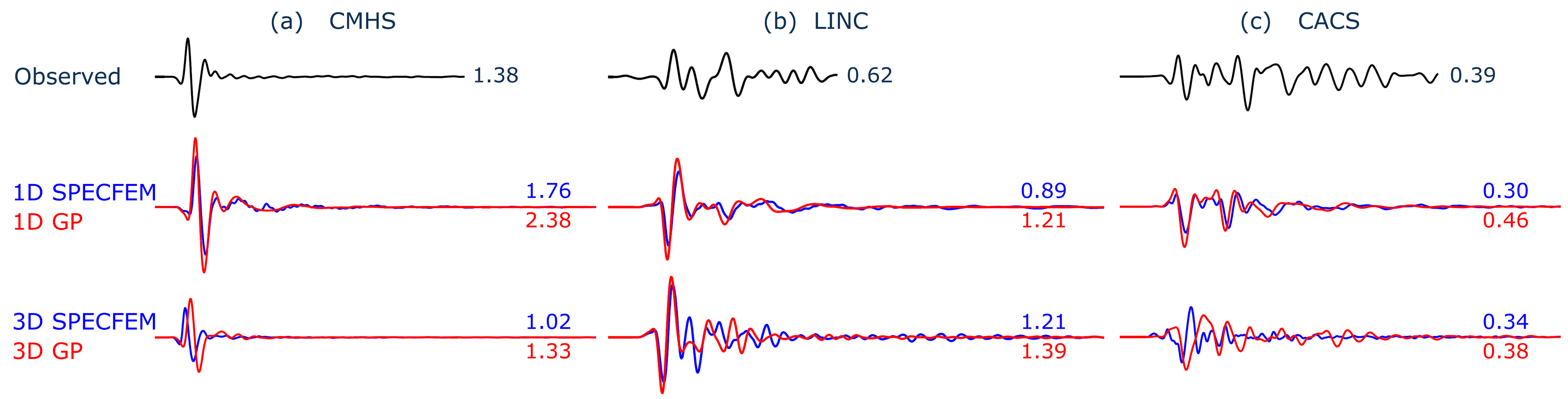

Figure 4: Comparison of observed, 1D simulated and 3D simulated ground motions for the (a) Cashmere high school site (CMHS), (b) Lincoln site (LINC) and (c) Christchurch Aero Club site (CACS), for the 19th October 2010 M_w 4.8 event. Included are the corresponding maximum velocities in cm/s.

4. Future Work

In the future, the current workflow being developed for tomographic waveform inversion for the Canterbury region will be extended to a South Island wide application.

Figure 5 presents the entirety of the South Island of New Zealand with locations of small-to-moderate M_w events, strong motion stations, and ray paths of observed ground motions. The areas for the current Canterbury earthquake sequence (CES) and South Island simulations are also shown. The coverage of ray paths are concentrated around the areas of high seismicity such as along the Alpine Fault and the Canterbury plains. The improved South Island velocity model will then be used to simulate large-scale scenario fault ruptures such as Alpine Fault ruptures.

Additionally, the inversion methodology in SPECFEM3D after Tape et al. (2009) only considers arrival times of wave packets. In the future, there is potential for investigating methods which consider the full waveform, both arrival times and amplitudes of wave packets, such as Chen et al. (2007,2010) and beyond.

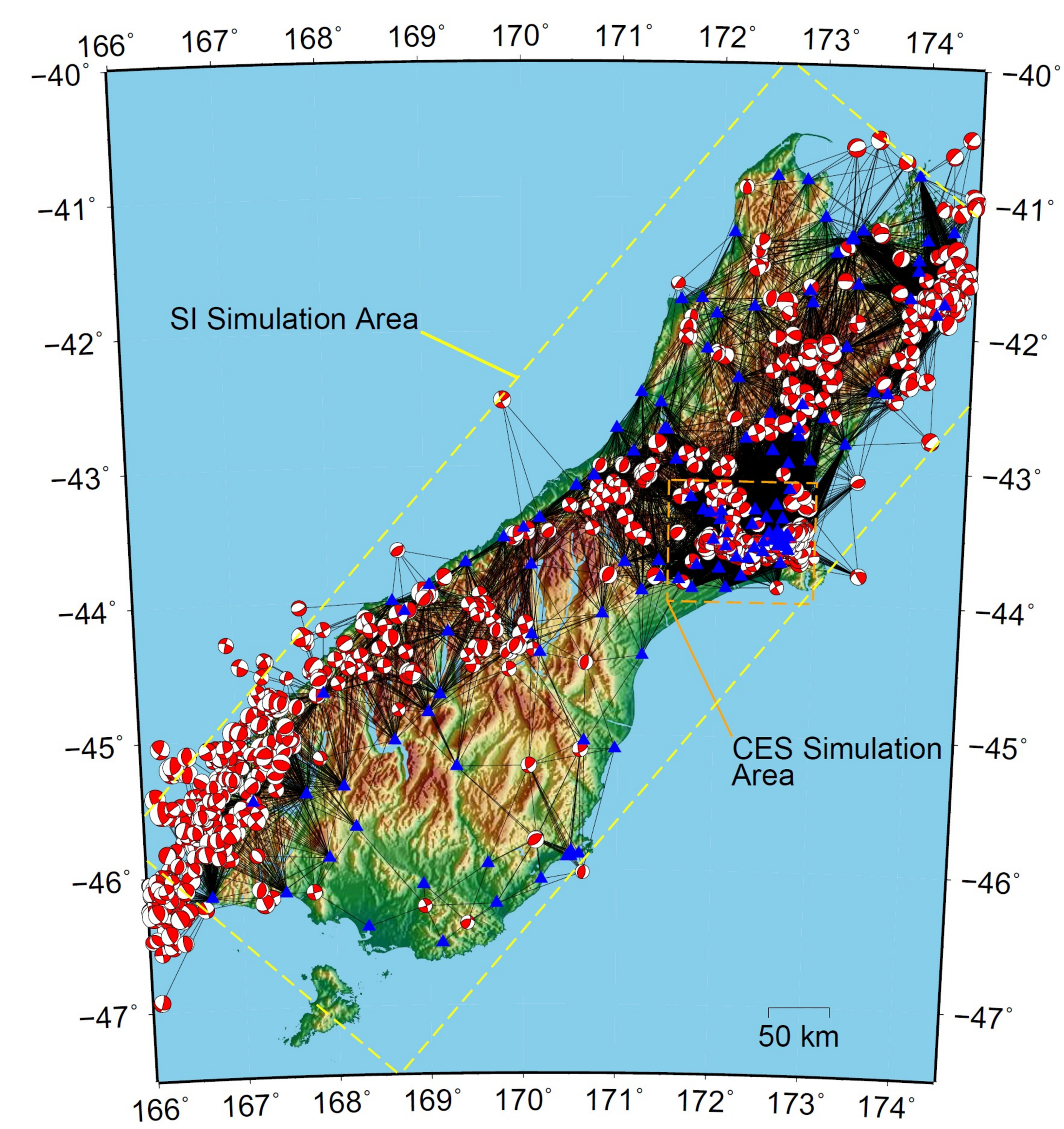

Figure 5: Seismic sources and strong motion stations in the South Island of New Zealand, and corresponding ray paths of observed ground motions.